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THE CAPRONI SEAPLANE.

By

Max Munk,
National Advisory Committee for Aeronautics.

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The science of aerotechnics is not yet so far advanced as to give beforehand complete information concerning all the qualities of a projected aircraft. Indeed, we doubt whether the science will ever be developed so far. A new project will always be a risk, and to a much higher degree as the project differs from those which have hitherto turned out well. The final judgment can not be given before the project is put into execution.

However the science of aerotechnics is able to give a certain amount of useful information concerning a new project. The greater the risk of a new project, the more desirable is it to apply this information which the science is able to give, and thus to diminish the unavoidable risk as far as possible. Aerodynamics in its present state is well able to give valuable hints for the development of aircraft, and to show beforehand the certain failure of many a project, the money and time for the execution of which could better have been saved or employed for a more promising project.

The Caproni Company recently built a seaplane of unusual design, the picture of which was published in most aerotechnical journals. The main supporting surfaces consisted of three triplanes in tandem, the lower wings being attached to a hull which was described as providing accomodation for a hundred passengers. The chief characteristics were:

Total weight	53,000 lbs.
Total horsepower	3,200 HP
Total wing surface	7,770 sq.ft.
Span	108 ft.

At one of the first flights the seaplane fell into a lake, nose down, and was destroyed.

We wish to show in this paper that this failure could have been predicted. It is not intended to examine the details of the airplane which are not yet known to us. We will only consider in certain respects and in a rough manner the performance to be expected, and examine in a manner as rough., but quite sufficient for the present purpose, the longitudinal stability, the lack of which has caused the loss of the seaplane.

The Performance.

The parasite "drag" of the seaplane, with respect to the dynamical pressure including the parasite drag of the wings, that is to say, the entire drag of the seaplane excepting the induced drag of the wings, can be assumed to be $c_D\ S \cdot q$, where S denotes the entire area of the wings, c_D a constant which can be roughly estimated to be .04 for the Caproni seaplane, and $q = 1/2\ \rho\ V^2$, the dynamical pressure corresponding to the velocity of flight V and to the density of the air ρ. The induced drag is*

$$\frac{L^2}{b^2\ \ q\ \ \pi}$$

L denoting the entire weight, and b the span of the wings. The gap of the triplanes is not taken into consideration in this expression, but for the present rough estimation it can be omitted. The entire drag is the sum of the two, i.e.,

(1) $$D = c_D\ S\ .\ q + \frac{L^2}{b^2\ \ q\,\pi}$$

Let η be the efficiency of the propellers. Then the thrust horsepower is

(2) $$P\ .\ \eta = V\ [\, c_D\ .\ S\ .\ q + \frac{L^2}{b^2\ \ q\,\pi}\ ]$$

q, the dynamical pressure, $1/2\ \rho\ V^2$, contains the square of V., ρ the density, depends chiefly on the altitude and decreases about 3.2% for each thousand feet. In the present calculation we will assume sea level. For constant density and a particular airplane the value of the right had side of (2) depends only on the velocity V; and (2) can be considered as an equation with one unknown quantity, if the horsepower is given. By solving it the greatest velocity possible is obtained. This solution is performed most conveniently by substitution and trial.

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* See Report No. 114.

Equation (2) holds true only if the seaplane is flying at a constant height. If it is climbing, the energy required to make it rise must be supplied by the propellers. The flight velocity will accordingly be smaller. The vertical velocity has its greatest value when the power required for supporting the seaplane is smallest. For then the difference between the power delivered by the propellers and that absorbed by the seaplane, is largest; and it is this difference which is at disposal for climbing. Hence it is useful to know the value of the smallest required power and at what velocity it occurs. We obtain the condition of smallest power by differentiating the expression of the power, the right hand side of (2), with respect to the velocity V

(3) $$0 = 3\, c_D\, S\, q - \frac{L^2}{b^2\, q\, \pi}$$

These are the equations which we intend to apply. By substituting the particular values and choosing feet, pounds and seconds as units, but using m.p.h. as unit of velocity, we obtain from equation (2):

(2a) $$\frac{3{,}200 \times 550 \times 0.7}{1.47} = 0.04 \times 7770 \times \frac{1}{390} \times V^3 + \frac{53{,}000^2}{108^2} \times 390 \times \frac{1}{\pi} \times \frac{1}{V}$$

(2b) $$1{,}840{,}000 = 796\, V^3 + \frac{29{,}900{,}000}{V}$$

That is, V = 85 mi./hr., the maximum velocity of flight. The differentiation of the right hand side of (2b) gives

(3a) $$2.39\,V^2 - \frac{29,900,000}{V^2} = 0$$

$$V = \sqrt[4]{\frac{29,900,000}{2.39}} = 59.5 \text{ mi./hr.}$$

The required power at this velocity is

(2c) $$\eta\,P = [0.796 \cdot 59.5^3 + \frac{29,900,000}{59.5}]\,\frac{1.47}{550} = 1,810 \text{ HP}$$

The entire available power, if the efficiency of the propellers is taken as 70%, is 3,200 x 0.7 = 2,240 HP; so there remains for climbing

2,240 - 1,810 = 430 HP

The rate of climbing is $\frac{P}{L} = \frac{430 \times 550}{53,000} = 4.5$ ft./sec.

This corresponds to 220 seconds for 1000 feet.

The calculation, of course, is only rought, and can give only an indication as to the performance to be expected. The calculation could be improved very much if more details were known and taken into consideration. For the present purpose, however, the result is exact enough.

The Longitudinal Stability.

At first sight the dimensions of the C aproni seaplane seem almost to be incompatible with longitudinal stability. Any section of wing used in practice has a forward motion of the center of pressure, if the angle of attack is increased. Hence they are longitudinally unstable and require a special contrivance for counterbalancing, ordinarily a tail plane. The Caproni seaplane has no tail and no special tail plane.

Now it is true that the third triplane can act as a tail plane if its angle of attack is correspondingly smaller than those of the first two triplanes. In this case the first two triplanes must support the craft almost by themselves, and the third triplane acts only as stabilizer. But even then it seems doubtful whether the instability of the wings can be counterbalanced, as a tail plane is only able to be effective if there is not too much wing area in front of it.

For the present purpose it is sufficient to show this for a monoplane with a tail plane behind it. The result obtained for it can be regarded as the first approximation for any other arrangement. of wings.

The tail plane is situated in the downwash produced by the wing in front of it. Its effective angle of attack accordingly is smaller than the actual (or geometrical) angle of attack. The difference equals the angle between the direction of flight and the direction of flow of the surrounding air relative to the airplane. Hence the lift is generally smaller than it would be without the existence of the downwash.

Let this difference between the actual and the effective angle of attack be called the "induced angle of attack", it being caused by the wings in front of the tail plane. It is proportional to the coefficient of lift of the wings, and at the same time, to the actual angle of attack of the tail plane. Whence it follows that the ratio of the actual and the effective angle of attack is constant and independent of the angle or the velocity. The percentage by which the effective angle of attack is smaller than the actual angle is practically constant for a particular airplane and depends only on the dimensions of the airplane.

The more wing area in front of the tail plane, the greater is the ratio of the induced angle to the actual angle, and if the area increases more and more, we arrive at last at a limit, where the induced angle is as great as the actual one. In this case the effective angle is zero, and the tail plane has always the same angle of attack with respect to the air surrounding it. Hence it can no longer produce stabilizing forces. If the area of the wings is increased still more, the effective angle even becomes negative and the airplane is less stable with the tail plane than without it.

To make this idea practically useful, we will proceed to calculate the ratio of the two angles. This can be done approximately in general. At small angles of attack the coefficient of lift of the usual sections, $\frac{L}{S \cdot q}$, increases by about 0.1, if the effective angle of attack increases by 1°. This effective angle is not identical with the actual angle. Even if there is no other body in the neighborhood, the wing is surrounded by downwash produced by itself. The angle of attack corresponding to this downwash is properly called the "self induced" angle of attack. For a particular coefficient of lift the effective angle of attack must be increased by this self-induced angle in order to obtain the actual angle. The self-induced angle of attack has a magnitude*

$$(4) \qquad \alpha_i = \frac{L}{\pi \ b^2 \ q} \times 57.3^\circ = \frac{c_L \ S}{\pi \ b^2} \times 57.3^\circ$$

as is proved and demonstrated elsewhere.** The angle of attack induced at some distance behind the wing has almost twice this magnitude. The mathematical theory gives exactly twice the magnitude, and experiments have shown a magnitude of about 10% less than twice the self-induced angle.

That is all we need. For, increasing the coefficient of lift by a certain amount Δc_L, the effective angle of attack must be increased by 10°. Δc_L^o, the self-induced angle increases by $\frac{57.3^\circ}{\pi} \frac{S}{b^2} \Delta c_L$, and therefore the actual angle must be increased by the sum of these;

$$(5) \quad \Delta \alpha = \Delta c_L \left[10^\circ + \frac{57.3^\circ}{\pi} \cdot \frac{S}{b^2} \right]$$

The induced angle of attack behind the wing at the same time increases by

$$(6) \quad 2 \Delta \alpha_i = 2 \Delta c_L \frac{57.3^\circ}{\pi} \cdot \frac{S}{b^2}$$

The increase of the effective angle of attack of the tail plane is the difference between (5) and (6), that is

$$(7) \qquad \Delta \beta = \Delta c_L \left[10^\circ - \frac{57.3}{\pi} \frac{S}{b^2} \right]$$

The tail plane is ineffective if the expression in the brackets is zero. In order to obtain a stabilizing effect we

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* Technische Berichte, Vol. II, p. 187.

** Report No. 114.

must have

(8) $\qquad \frac{S}{b^2} < 0.55$

If we take the smaller amount of the downwash behind the wings, obtained by actual tests, we obtain as a limit

(8a) $\qquad \frac{S}{b^2} < 0.7$

(8) and (8a) are the formulas we alluded to. The same consideration also holds true for a more complicated system of wings. It is true that the right hand limit in (8) is then somewhat changed. But the new value is not greatly different from it and the first examination can be made with formula (8)

For the Caproni seaplane $\frac{S}{b^2} = \frac{7770}{108^2} = 0.68$

That is about the limit set by (8a). It would be necessary therefore to examine the effectiveness of a tail plane behind the triplane more carefully. In any case, this tail plane must be unusually large in order to neutralize the considerable decrease of the effective angle of attack caused by the downwash.

Now the Caproni seaplane has no tail plane behind the third triplane and we therefore can omit this examination. If we consider, on the other hand, the third triplane to act as a big tail plane, we have only to take into account the wing area in front of it. This is only 2/3 of the complete area; that is, $M\frac{S^2}{b}$ is only .43 and it may be possible that the balancing capacity of this big tail plane would be sufficient. But we see that even the wing area in front of the last triplane is by no means very small when compared with the limit determined above.

However, the third triplane acts only as a tail plane under the condition that its actual angle of attack is considerably smaller than those of the two other triplanes. The first two triplanes must support the craft almost by themselves. The center of gravity accordingly must lie between the first two triplanes, at least near the middle point between them. The arrangments of the different parts of the Caproni seaplane, however, indicate that the center of gravity does not lie there, but that it is in the neighborhood of the second triplane. The third triplane is not constructed as a tail plane but is designed to support one-third of the craft. This can be seen from the photographs of the seaplane.

The center of gravity of the empty hull is obviously near the second triplane. The 100 passengers seem to be distributed along the hull; its length, according to the photographs, is about 60 ft., its breadth seems to be nor more than 8 ft. The floor area is about 480 sq.ft., that is, not even 5 sq.ft. for one passenger. It can not be much less. The windows of the hull also justify the assumption that the whole is occupied by the passengers. The weights of the three triplanes obviously are equal, and their positions are such that their common center of gravity is in the neighborhood of the second triplane. The craft has eight engines which drive six propellers. The photograph shows four engines driving three propellers in front of and within the first triplane, and an equal aggregate at the third triplane. Their common center of gravity also lies in the neighborhood of the middle of the seaplane. There remains only the fuel. Its weight even at the beginning of the flight is not great enough to change the position of the center of gravity very much. If the number of passengers is really 100, the craft can only carry a small quantity of fuel in any case. At the end of the flight the weight of the fuel is certainly small, and then it can not influence the position of the center of gravity considerably.

We think that by all these facts the position of the center of gravity in the middle of the craft is sufficiently demonstrated. In this case, the seaplane is excessively unstable, It is not necessary to mention that the instability of the three single triplanes adds up and is in no way counterbalanced. The three triplanes form as it were, one big wing which as a whole is unstable beyond measure.

In a certain state of flight let there be equilibrium, no matter whether produced by the effect of the controls or by different angles of attack of the triplanes. Now, let the angle of attack to be slightly increased and consider the increase of the lift of the three triplanes as a consequence. In this paper we intend to simplify the theoretical connections as far as possible, preferring greater clearness to a greater exactness in the result. For this reason, it will be assumed that the wing or triplane induces no downwash on any wing <u>in front</u> of it, and in fact, the induced downwash in front is not great. The induced angle of attack on the wing <u>behind it</u> shall be assumed to be twice the self-induced angle of attack.

Let $\Delta\alpha$ be the increase of the angle of attack. The increase of the actual angle of attack of each of the three triplanes is identical with $\Delta\alpha$, but the increase of the effective angles is smaller. For the first triplane the increase of the self-induced angle of attack is

$$\Delta\alpha_i = \frac{57.3}{10 \cdot \pi} \cdot \frac{S}{b^2} \cdot \Delta\beta_1 \text{ say } = m\,\Delta\beta_1$$

where $\Delta\beta_1$ denotes the increase of the effective angle of attack and

$$m = \frac{57.3}{10. \pi} \quad \frac{S}{b^2} \qquad \text{(Definition)}$$

Hence, the increase of the effective angle of attack is

$\Delta\beta_1 = \Delta\alpha - m\,\Delta\beta_1$, and therefore

$$\Delta\beta_1 = \frac{\Delta\alpha}{1+m} \qquad \text{(compare (5)).}$$

The second triplane not only experiences the increase of its self-induced angle of attack $m \cdot \Delta\beta_2$ but also the induction of the first triplane $2\,m\,\Delta\beta_1 = \frac{2\,m}{1+m}\,\Delta\alpha$. The increase of its induced angle of attack is

$$\frac{2m}{1+m}\,\Delta\alpha + m\,\Delta\beta_2 = \Delta\alpha - \Delta\beta_2, \text{ hence}$$

$$\Delta\beta_2 = \Delta\alpha\,\frac{1-\frac{2\,m}{1+m}}{1+m} = \Delta\alpha\left[\frac{1}{1+m} - \frac{2\,m}{(1+m)^2}\right]$$

For the third triplane with the increase of the induction

$$m\,\Delta\beta_3 + \Delta\alpha\left[\frac{4\,m}{1+m} - \frac{4\,m^2}{(1+m)^2}\right] = \Delta\alpha - \Delta\beta_3$$

the increase is

$$\Delta \beta_3 = \Delta\alpha \frac{1 - \frac{4\,m}{1+m} + \frac{4\,m^2}{(1+m)^2}}{1+m} = \Delta\alpha \left(\frac{1}{1+m} - \frac{4\,m}{(1+m)^2} + \frac{4\,m^2}{(1+m)^3}\right)$$

The lift of the three triplanes increases proportionally to these calculated increases of the angles of attack. If the center of gravity is assumed to be situated at the second triplane, the increase of the lift of the third triplane does not counterbalance that of the first. If the distances between the three triplanes are equal and denoted by l there remains a moment which is not counterbalanced

$$M = l\ \Delta\alpha\ .\ 5.73\ \frac{S}{3}\ .\ q\ \left[\frac{4\,m}{(1+m)^2} - \frac{4\,m^2}{(1+m)^3}\right]$$

where, S/3 is the area of one triplane and q the dynamical pressure.

For the Caproni Seaplane

$$m = \frac{57.3}{10\,\pi} . \frac{S}{3b^2} = \frac{57.3}{10\,\pi} . \frac{\frac{1}{3}\ .7770}{108^2} = 0.4$$

$$M = \Delta\alpha\ .\ l\ .\ q\ .\ 7,100$$

For $q = 20\ \frac{\text{lbs.}}{\text{sq.ft.}}$, $l = 14$ ft., we obtain

$$M = \Delta\alpha\ .\ 1,980,000 \text{ lbs. ft.}$$

The moment of inertia of the seaplane with respect to the center of gravity and the horizontal axis from left to right may not be very different from 150,000 lbs. ft. sec². The time required to increase a deflection to the "e" fold of the original value is

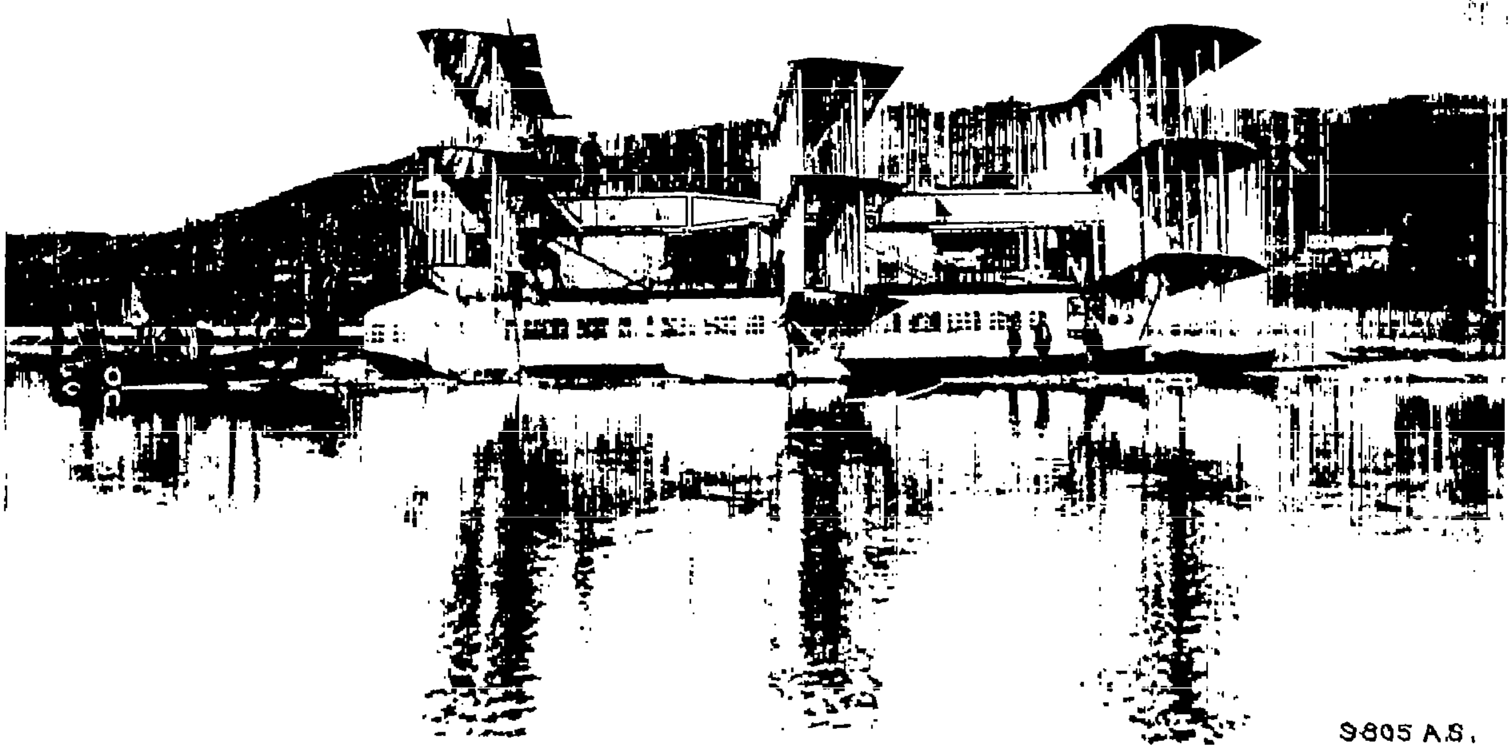
$$\sqrt{\frac{150,000}{1,980,000}} = .27 \text{ sec.}$$

The instability due to sections of the wings is not taken into account in this discussion.

In spite of this great instability, there is no danger if the angle of attack has become very high. For at a very high angle of attack the lift of the first triplane ceases to increase and then the airplane is in stable equilibrium. There can however be no stability for small angles; and in this manner the accident is said to have occurred.

The calculation which we have made does not claim to give an accurate result. It is only roughly made. The entire theory of stability is not yet very far developed. We do not even know how great an instability is allowable without endangering the airplane.

Experience has shown, however, that an airplane can be allowed to be only slightly unstable. The instability due to the change of the center of pressure of the wings is too great already and must be counterbalanced. The preceding calculations show that the Caproni Seaplane was exceedingly unstable. An accident as that which really occurred at one of the first flights or at the first flight perhaps, is not, therefore, surprising or unexpected.



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